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Aerodynamic drag measurement of American footballs

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Abstract

The flight trajectory of an American football largely depends on its aerodynamic characteristics. Despite the popularity of the game, it appears that little information on the aerodynamic force experienced by an American football, especially under crosswinds is available in the open literature. The shape of an American football is similar to that of an ellipsoid. It has more pointed ends and has a rough surface. The ball used in college level teams possesses a pair of seams at each of pointed ends. All these features and crosswind make the airflow around the ball more complex. The primary purpose of this study is to experimentally measure the aerodynamic forces of professional (NFL) and College levels (NCAA) American footballs under a range of wind speeds and yaw angles. The non-dimensional drag coefficients were determined and compared. The results indicate that the American footballs possess drag coefficient close to that of other oval shaped balls such as Rugby and Australian rule footballs. It also shows that the drag coefficient can be almost four times higher under crosswinds.

Keywords: American football; drag; wind tunnel; yaw angle; flow visualisation; NFL; NCAA

1. Introduction

American Football is one of the most popular sports in North America. The sport is commonly known worldwide as Gridiron. The football game is played and watched by millions of people and the ball remains central piece of it. The shape of an American football is similar to that of an ellipsoidal projectile such as Rugby and Australian Rules football with rough surfaces and more pointed ends. The ball used in college level games administered by the National Collegiate Athletic Association (NCAA) possesses a pair of semi-circular seams at the pointed ends. This can make the airflow around the ball even more complex and asymmetric. The ball used in professional games administered by the National Football

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League (NFL) has no such pair of seams at the pointed ends. The flight trajectory of an American football largely depends on its aerodynamic characteristics. Despite the popularity of the game, it appears that very limited information on the aerodynamic forces experienced by the ball is available in the open literature. Although attempts were made to construct the flight trajectory of the ball, without knowing the aerodynamic properties such as drag coefficient, it is extremely hard to build such a model. Although several studies were undertaken by Rae [1], Rae & Streit [2], Brancazio [3], Watts & Moore [4], and Horn & Fearn [5] on aerodynamics of American footballs over the last two decades, no reliable aerodynamic forces data, except those by Rae & Streit [2] and more recently by Alam et al. [6] have been reported. The reported drag coefficient varies from 0.05 to 0.3 when the major axis is pointed into the wind. The drag coefficient of an American football under crosswinds is not available in the open literature at all. The shape of an American football makes more complicated flight trajectory than that of the spherical ball. The aerodynamic behaviour of spherical and other oval shaped sports balls has been well studied by Alam et al. [7, 8, 9], Asai et al. [10] and Mehta et al. [11, 12]. As mentioned earlier, no in-depth aerodynamic studies have been undertaken on American footballs despite its great popularity. Due to its complex shape, the airflow around an American football is believed to be significantly complex and little understood. As a result, the accuracy of long distance kicking/punting by elite level players to the desired point/goalpost is very low. A statistical study conducted by Hopkins [13-14] reported that the accuracy of kicking of oval shape balls to the goal post is close to 50% and not much has been improved over the last three decades although numerous efforts have been made. A comprehensive aerodynamics study therefore is paramount to understand the balls' behaviour in flight and subsequently build flight trajectory models of the ball for players and coaches so that they can develop better game strategy. However, the work is challenging, time consuming and costly. The primary purpose of this study is to experimentally measure the aerodynamic forces of NFL and NCAA footballs under a range of wind speeds and yaw angles (to simulate the effects of crosswinds).

Nomenclature

D	Aerodynamic drag
Re	Reynolds number, $\mathrm{Re} = \dfrac{\rho V d}{\mu}$
ρ	Air density
V	Air velocity
d	Diameter of the ball measured at mid point
μ	Dynamic viscosity

2. Experimental Procedure

2.1. Description of balls

Two new American footballs that are officially used in National Football League (NFL) and National Collegiate Athletic Association (NCAA) games are selected for this study. Their physical properties are shown in Table 1. Both balls were inflated with 13 psi (89.6 kPa) pressure. They were made of four leather segments as shown in Figures 1 and 2. It should be noted that the NCAA ball has 2 semi-circular stitch rings on the upper side of both conical ends as illustrated in Figure 2.

(a) Top view (b) Side view

Fig. 1. NFL game ball

(a) Top view (b) Side view

Fig. 2. NCAA game ball

2.2. Experimental facility

In order to measure the aerodynamic properties of both balls experimentally, the RMIT Industrial Wind Tunnel was used. The tunnel is a closed return circuit with a maximum speed of approximately 150 km/h. All three forces (drag, lift and side force) and their corresponding moments were measured. Experimental set ups for both balls are shown in Figure 3 and Figure 5. More details about the tunnel can be found in Alam et al. [15]. Tests were conducted at a range of wind speeds under ±90° yaw angles to simulate the crosswind effects. Yaw angle can be defined as the angle between the ball centreline (longitudinal axis) and the mean direction of airflow experienced by the ball. A sting mount was designed to hold each ball as shown in Figure 3. The distance between the bottom edge of the ball and the tunnel floor was 235 mm, which is well above the tunnel's boundary layer and the ground effect is considered to be insignificant. The aerodynamic forces and moments were measured under a range of wind speeds (40 km/h to 130 km/h with an increment of 20 km/h) and yaw angles (±90° with an increment of 15°). The non-dimensional parameter such as drag coefficient (C_D) was calculated from the measured data. The tare forces were removed by measuring the forces on the sting in isolation and removing them from the force of the ball and sting. The repeatability of the measured forces was within ±0.01 N and the wind velocity was less than 0.5 km/h.

Table 1. Physical parameters of the balls tested

	NFL ball	NCAA ball
Length, mm	280	280
Circumference (longitudinal), mm	700	690
Circumference (lateral), mm	530	530
Mass, gm	410	395
Air pressure, psi	13	13
Panel numbers	4	4
Panel surface	Leather	Leather
Surface finish	Rough with pimples	Rough with pimples
Lace exposed	Yes	Yes
External shape	Oval with conical ends and no stitch ring	Oval with conical ends and 2 semicircular stitch rings on upper side

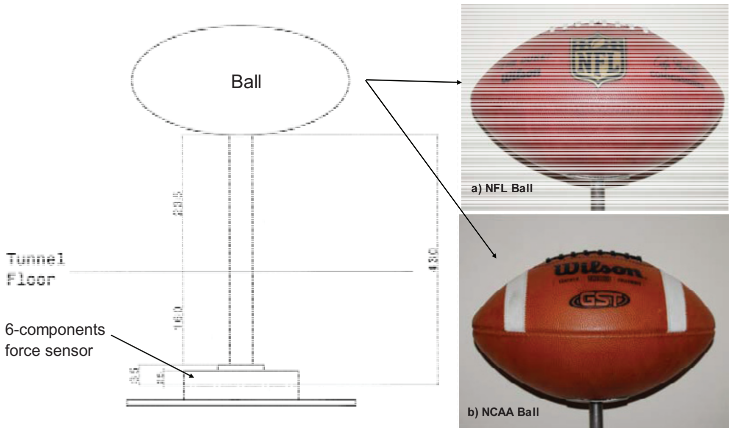
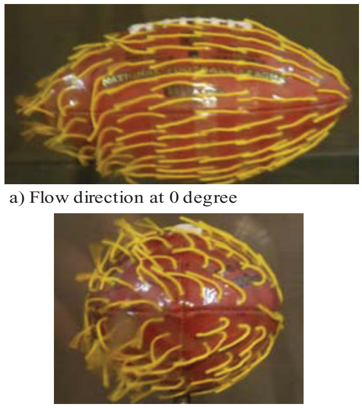


Fig. 3. Schematic of experimental set up (All dimensions are in mm)



a) Flow direction at 0 degree

b) Flow direction at 90 degree

Fig. 4. Airflow structure around NFL balls

a) NCAA ball in wind tunnel at 0° yaw angle

b) NFL ball in wind tunnel at 90° yaw angle

Fig. 5. Experimental set up in RMIT Wind Tunnel

3. Results and Discussion

The drag force coefficient (C_D) for both balls were plotted against yaw angles and presented in Figures 6 and 7. The C_D values for the NFL and NCAA balls at zero yaw angles are 0.19 and 0.20 respectively. At zero yaw angle, the NCAA ball displayed slightly higher drag coefficient than the NFL ball. This slight increase is believed to be due to the surface profile of the NCAA ball. The drag coefficient for both balls increases with an increase of yaw angles due to a larger and very complex flow separation. The average C_D values at +90° (windward side) yaw angle for the NCAA and NFL balls are approximately 0.75 and 0.78 respectively. The C_D values at -90° (leeward side) for the NFL & NCAA balls are 0.75 and 0.77 respectively. The negligible asymmetry in C_D values was found for the NCAA ball. However, slight asymmetry in C_D values was noted for the NFL ball (0.78 & 0.77). No significant Reynolds number (varied by wind speeds in this study) dependency was found at zero yaw angle for both balls. However, significant Reynolds number (Re) variations are noted at yaw angles over 50°. With the increase of speeds (e.g. Reynolds numbers), the variation becomes negligible (e.g., at 100 km/h and over) due to either elimination or minimisation of local flow separation. The asymmetry in C_D values is minimal for the NCAA ball whereas a slight asymmetry was noted for the NFL ball. Moreover, the NFL ball also shows a slight Reynolds number variation between -20° to -50° yaw angles. Such variation was not observed for the NCAA ball. It is difficult to compare C_D values at 0° yaw angle with the published data as most of these data are unreliable and often contradictory [4, 5]. The only reliable C_D data reported to the public is due to Rae and Streit [2]. Their measured C_D value at 0° yaw angle is around 0.16 which is very close to the findings of this work (0.19 & 0.20). However, there are no C_D values for the NFL and NCAA ball yet reported in the literature except the values reported here and Alam el at. [6]. Similarly no C_D values have been reported for NFL and NCAA balls when the minor axis is pointed into the wind (e.g., ±90° yaw angles). The graphs for C_D values for both balls show that the NFL ball displays the C_D values in relatively narrow band compared to the NCAA ball (see Figures 6 and 7). It was still not quite clear why this discrepancy had occurred. It might be due to the slight variation in dimensions and the presence of two semi circular stitches on two upper cone sides of the NCAA ball. A comparison of C_D values reported by various researchers is shown in Table 2.

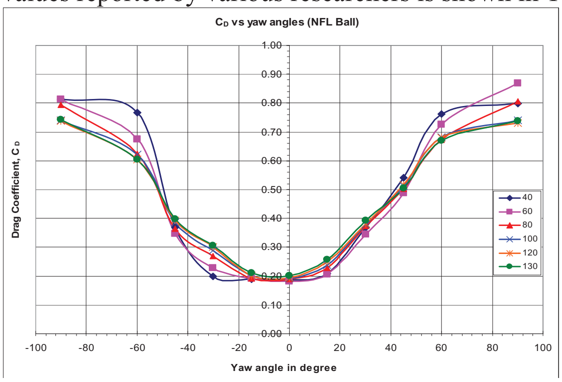


Fig. 6. C_D variation with yaw angle (NFL ball)

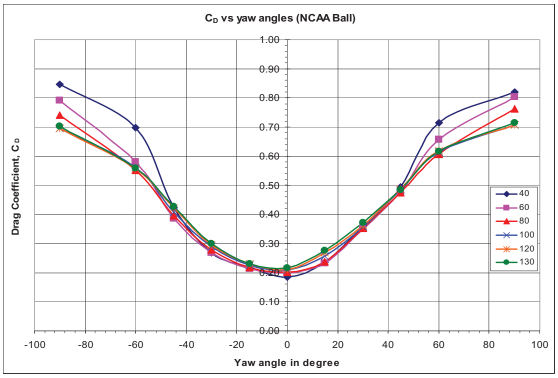


Fig. 7. C_D variation with yaw angle (NCAA ball)

The airflow structures around both balls are complex and three dimensional. The airflow appears to be separated ¾ length downstream from the nose when the longitudinal axis of the ball is aligned with the wind direction, i.e., at 0° yaw angle (see Figure 4a). However, the separated flow is fully three dimensional when the lateral axis of the ball is aligned with the wind direction, i.e., at 90° yaw angle (see Figure 4b). The side force coefficients (C_S) for both balls displayed a similar pattern (data not shown here for brevity).

Table 2. Comparison of data from current study and published literature

Football Type	Theoretical Ellipsoidal Assumption	NFL ball	Foam /rubber made ball	NFL ball	NCAA ball
Published data	Brancazio [3]	Rae & Streit [2]	Watts & Moore [4]	Current study	
Min C_D at 0° yaw angle	0.10	0.16	0.05 – 0.06	0.19	0.20
Max C_D at 90° yaw angle	0.60	0.85	N/A	0.75	0.78

4. Conclusions

The average drag coefficient for American footballs is in the range of 0.18 to 0.20 when the major axis of the ball is pointed to the wind direction and 0.75 to 0.78 when the minor axis is pointed to the wind direction. The NCAA ball possesses slightly higher value of drag coefficient compared to the NFL ball. The effect of crosswind on aerodynamic drag is significant as the drag coefficient can be four times higher under ±90° yaw angles. The Reynolds number dependency is noted for both balls at yaw angles over ±50º.

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